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ABSTRACT

SCALE-UP is an extension of the highly successful IMPEC (Integrated Math, Physics, Engineering, and Chemistry) project, one of North Carolina State's curricular reform efforts undertaken as part of the SUCCEED coalition. The authors utilize the interactive, collaboratively based instruction that worked well in smaller class settings and find ways to economically accommodate classes of up to 100 students. Relative to students taught in traditional classes, SCALE-UP students are better problem solvers, achieve nearly four times the gain on some conceptual tests, have better attitudes toward science, and report greater satisfaction with tier instruction. Failure rates for females are half those in regular classes. For minorities, the failure rate drops by a factor of four. Technology is used to provide a phenomenological focus for students, allowing data collection, analysis, mathematical modeling, and advanced simulations. As student attention is drawn into analyzing different physical situations, teachers circulate around the room and engage students in Socratic dialogs. Lecturing is minimal, primarily for motivation and to provide an overview of topics. The main objectives of the course are presented along with a discussion of some of the instructional techniques employed. (Contains 39 references.) (DDR)

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Session 2380

Introduction to SCALE-UP : Student-Centered Activities for Large Enrollment University Physics

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Abstract

SCALE-UP is an extension of the highly successful IMPEC project (Integrated Math, Physics, Engineering, and Chemistry), one of NC State's curricular reform efforts undertaken as part of the SUCCEED coalition. Basically, we are utilizing the interactive, collaboratively based instruction that worked so well in smaller class settings and finding ways to economically accommodate classes of up to 100 students. Relative to students taught in traditional classes, SCALE-UP students are better problem solvers, achieve nearly four times the gain on some conceptual tests, have better attitudes toward science, and report greater satisfaction with their instruction. Failure rates for females are half those in regular classes. For minorities, the failure rate drops by a factor of four. Technology is used to provide a phenomenological focus for students, allowing data collection, analysis, mathematical modeling, and advanced simulations. As student attention is drawn into analyzing different physical situations, teachers circulate around the room and engage students in Socratic dialogs. Lecturing is minimal, primarily for motivation and to provide an overview of topics. The main objectives of the course will be presented, along with a discussion of some of the instructional techniques we employ.

I. Introduction

A common complaint of students entering a large university like NC State is the impersonal atmosphere of their large, lecture-oriented classes. Sections of at least 100 students are an economic necessity since there simply are not enough teachers or classrooms to allow smaller class sizes. This is seen as a disadvantage by both students and faculty. It usually results in minimal contact between students and the professor. Students often feel "lost in the crowd." Teachers encounter low motivation and minimal student involvement with the material. Although students taking these courses often do reasonably well on traditional exams, research-based conceptual testing indicates a shallowness in their understanding. This has been clearly documented in numerous studies conducted across the country[4, 13, 20, 23, 24, 28, 31, 38] and has perhaps been most clearly

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stated by Arnold Arons:[2]

> "...I point to the following unwelcome truth: much as we might dislike the implications, research is showing that didactic exposition of abstract ideas and lines of reasoning (however engaging and lucid we might try to make them) to passive listeners yields pathetically thin results in learning and understanding–except in the very small percentage of students who are specially gifted in the field." p. vii

Of course, those few who manage to thrive within the current system are thus academically successful and often go on to careers in academia where they continue the tradition. A lack of exposure to other instructional possibilities, coupled with the general inertia of large universities, results in a stagnation of educational approaches. Many schools are grappling with this problem by modifying lectures[17, 26, 32, 35, 39, 40] or laboratory[5, 14, 27, 29, 34, 36] experiences. But because of well-established systems for presenting and grading standard lecture-oriented courses, change is not easy. Nonetheless, we know students are not learning as much as they should. There are often large gaps in their knowledge and what understanding they have is superficial and does not readily transfer to other areas. Additionally, employers often request that students be given opportunities to strengthen their communication skills and have special training in team approaches to problem solving. ABET has adjusted their accreditation standards[1] accordingly. Unfortunately, traditional lecture-oriented courses do not provide this type of instruction.

There is an ever-increasing trend toward actively involving students in their learning. Alexander Astin's study[3] "What Matters in College?" supports the view that faculty involvement with students and active, self-directed learning contribute more than anything else to measurable student success. Involvement with campus communities correlates with student success. This has led us to consider ways we can make our engineering physics courses, which begin during the critical freshman year, an environment where students can become more involved with the material, their peers, and their instructors.

I. Project Status

SCALE-UP is an extension of the highly successful IMPEC[6, 11] project (Integrated Math, Physics, Engineering, and Chemistry), one of NC State's curricular reform efforts undertaken as part of the SUCCEED coalition. We are in the third year of an effort to make large enrollment calculus-based introductory physics courses more effective. There have been three phases to the SCALE-UP project. The first phase was conducted in a traditional lecture hall with long narrow tables and fixed seating. We are currently in our Phase 2 implementation in a renovated room seating 54. Construction of a 99-seat Phase 3 classroom is currently underway with completion scheduled for late summer 2000. Preliminary blueprints for a new Physical Sciences Instructional Lab Building also include space for two SCALE-UP classrooms.

Project evaluation continues as a vital, on-going series of tasks. We have had a

researcher in the room during nearly every class of the previous academic year, writing field notes and capturing the interactions between students and with the instructors. Videotapes of each class are recorded for further analysis. Interviews with individuals and focus groups have been conducted throughout the project. These are providing great insight into how this type of learning environment is affecting students. We are continuing our attitude surveys, additional standardized testing, and comparisons to our Department's traditional classes.

II. Project Objectives

Some of what we hope to accomplish is listed below, along with our progress:

1. Design new modes of instruction for large enrollment sections

This objective concerns classroom management more than teaching materials. We are trying to develop techniques that will permit use of research-based pedagogies in large enrollment classes, even though many of these materials were originally created for small class settings. For example, we are trying different ways to utilize the *Tutorials*[25] developed by the Physics Education Research Group at the University of Washington. We have found that they must be broken up into short segments. Interspersing brief, classwide discussions makes sure everyone is spending a reasonable amount of time on each part of the activity and provides opportunities to address difficulties before any group gets too far behind.

Technology has been utilized as an organizer. Most course materials are available on the web, including the syllabus, a calendar, daily activities, and examples of notes and lab reports. *WebAssign*, NC State's web-based problem delivery system, is used both during and outside of classtime to present questions and problems for consideration. To ensure that students read the textbook and are well prepared for class, we use the system to assign questions and problems that are due just as those topics come up for discussion in class. If this was not done it might be difficult to cover all the standard topics in the depth we feel is necessary. The students are responsible for independently learning simple definitions and straightforward concepts, so time in class can be spent grappling with the more difficult ideas. Our software selection is based on a study[7] we have done of classrooms across the country. Java applets and simulations are a major part of our instructional methodology. While students work on these carefully constructed activities, the instructor and assistant are able to move about the room, asking and answering questions.

2. Create student "neighborhoods" within a large university

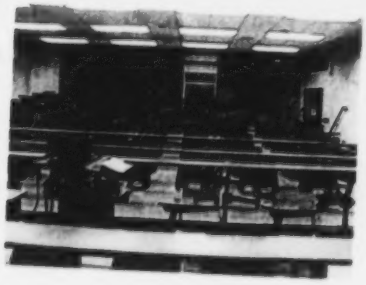
There is a substantial body of research indicating the value of collaborative learning[6, 10, 12, 18, 19, 22]. In the SCALE-UP classes we have students working in teams of three[9], which they keep throughout the semester. There are also times when students work in larger teams of nine. Each small team has their own computer, as described below. We have instituted rigid protocols to ensure participation by all group members. Group roles are

rotated and students regularly assess the "teamsmanship" of themselves and their teammates. We have also incorporated a "group bonus" that adds a few points to each team members exam score when the group average is above a specified minimum. This has worked very well to encourage involvement by the better students, who otherwise might feel "dragged down" by others in their group. Readers interested in more details are referred to the paper "Promoting collaborative groups in large enrollment courses" associated with poster session 1526.

3. Experiment with classroom layout

After trying rectangular tables and three different diameters of round tables, we have chosen tables with a diameter of 6 feet. (See Figures 1 and 2.) Tables that are much larger do not accommodate table-wide discussions. Smaller tables don't allow enough students to work together and are not space efficient. We believe 7-foot diameter round tables might permit a bit more room for students without being too large, but we could not accommodate the larger size in our available space. The technological components of the classroom have worked very well. We have had surprisingly few computer or networking problems. The projection system for the instructor's computer and the Elmo Visual Presenter has worked flawlessly. Students have no difficulty picking one of the two screens for convenient viewing. We are currently experimenting with software that allows the instructor screen (or a specified student laptop screen) to be displayed simultaneously on all the classroom computers. All syllabus material and daily schedules are kept on the class website. The majority of the activities are there also. We have found that laptop computers on the students' tables are an absolute requirement. In the IMPEC project (which utilized desktop computers) the monitors essentially eliminated within-table discussions by blocking lines of sight. Keeping the computers themselves below the tables reduced, but did not eliminate this problem. In addition, this stopgap measure meant that plugging in the computer interfacing equipment required crawling under the table to make the necessary connections. Switching to laptops has completely alleviated these difficulties. When the laptops are not needed or are causing a distraction, asking students to "close the lids" instantly removes the computers from the scene. We are strongly recommending to visitors that the extra cost of using laptops instead of desk computers is worth it. In comparisons with the Phase 1 classroom (basically a lecture hall with very long tables), we have also seen that continuous student access to computers is a vital part of the classroom environment. Basically, the technology provides a focus for the students, bringing their attention to bear on the physical phenomenon being examined, whether that study is conducted through data collection and analysis, constructing mathematical models, running a simulation, or gathering other relevant information. This frees the instructor, who doesn't have to always be in front of the classroom but instead can move about and talk with the students.

Figure 1 At left, the Phase Two classroom which accommodates 54 students. Nine students sit at each table in three teams of three. The Phase One classroom is below.



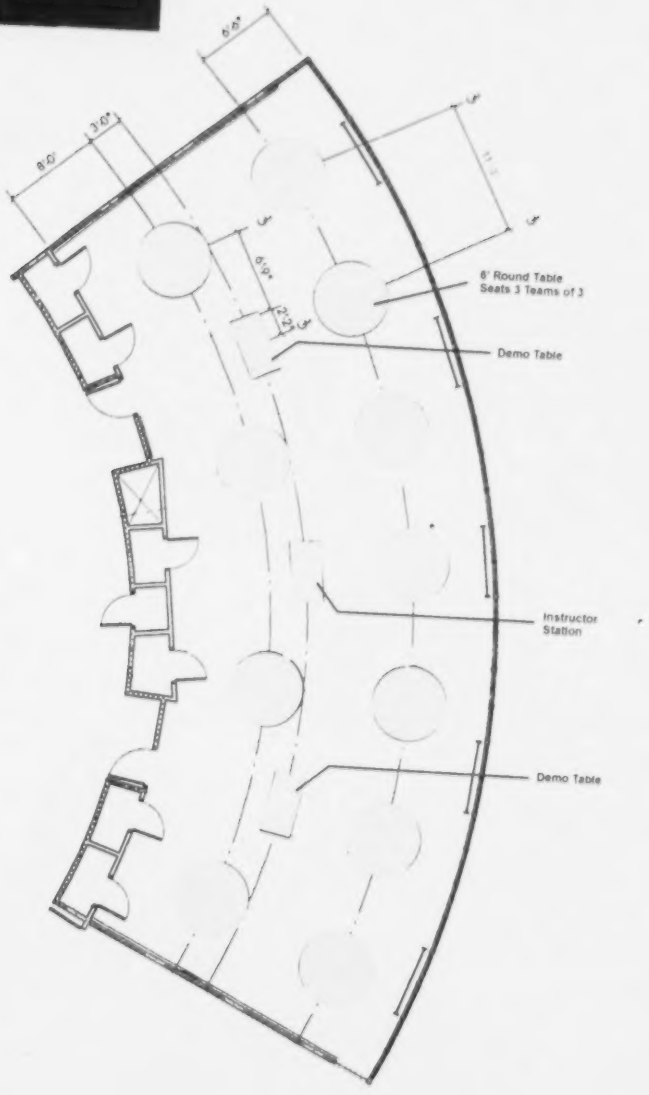


Figure 2 The Phase Three classroom for 99 students is scheduled for completion in late summer 2000. Note that an ideal room shape would be square with the instructor station in the center.

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4. Write instructional materials

We have developed a large series of what we call "tangibles" (short hands-on activities) and "ponderables" (interesting questions to consider). Most of these tasks are based on known areas of student difficulty. In addition to developing our own activities, we are also modifying existing materials, such as the Washington *Tutorials*[25], Dickinson's *Workshop Physics*[21], and Minnesota's *Cooperative Group Problem Solving*[15]. As an effort to move these ideas into the "mainstream," some original materials have been incorporated into Serway and Beichner's *Physics for Scientists and Engineers*, 5th ed.[33] This textbook and the accompanying Instructor's Manual and Student Guide also incorporate the GOAL problem solving protocol that is utilized throughout the SCALE-UP curriculum.

In addition to the short tangible activities, we also have more extensive, group-based laboratory work that requires a formal report. Following suggestions from the collaborative learning literature, as part of their lab each individual examines the teamsmanship of themselves and their group mates. The quality of their evaluation is worth 10% of the lab grade. We also have created practical lab exams where each student must demonstrate every skill required for a lab. This has worked well to insure that everyone gets an opportunity to use all the equipment and thoroughly understand all parts of the lab. Thus individual accountability and group responsibility are built into each lab activity.

As time goes on, we are more fully utilizing *WebAssign*, our system for posing questions and problems over the web for homework or to promote classroom discussion. It is also used to present students with anonymous conclusions from other groups' lab reports. By ranking the quality of these conclusions, students work at the top levels of Blooms' Taxonomy of Cognition[8]. We are using many of the *Physlets®* developed by Wolfgang Christian at Davidson College and we hope to create our own video analysis applet and perhaps a web-based simulation engine as well. The main advantage of this type of software is that it is readily available outside of class for student homework or review. Non-web-based applications require multiple user licenses or else students must go to a special computer lab where the software is available. Web-based applications are available on any computer (including those in dorm rooms) that has an Internet connection.

5. Create teachers' guides

We are taking the materials developed during the project and fitting them into a template that incorporates several important features, including objectives, known student difficulties, tasks to assign, reasons for assigning them, and pitfalls to avoid. We will continue to develop and modify these as we complete additional classroom trials. There has been widespread interest in the curriculum and redesigned classroom space. We have had more than 30 visitors so far this year, including faculty from four foreign countries.

6. Improve student learning

We have been looking at several different aspects of learning, including problem-solving, conceptual understanding, and even attitude development. We measured problem-solving skills by taking problems from the Department's common examinations and giving them to the SCALE-UP students. In the previous fall semester, the SCALE-UP students outperformed their peers 88% of the time. During the next semester we looked more closely at specific types of problems. We found that the SCALE-UP students had higher scores on 20 of the 29 common problems selected for comparison. When the traditional students did better, the problems tended to be one-step problems like simple unit conversion.

Conceptual understanding in the mechanics course is also greatly enhanced. Results on the Force Concept Inventory[16] (FCI) and the Force and Motion Conceptual Evaluation[17] (FMCE) have been very encouraging. According to a study[13] by Richard Hake, normalized gains on the FCI from pre-test to post-test for traditional mechanics classes average 23%. Our fall and spring semester mechanics classes averaged normalized gains of 43% and 52%, respectively. This compares vary favorably with the most successful innovative classes around the country, which were typically smaller classes. The spring semester class also posted fractional gains on the FMCE, an alternative mechanics-concept test, that were nearly four times higher than their peers in our traditional classes. We are beginning to see good gains (35%) in our electricity and magnetism course as well. Many additional details of our assessment effort can be found in the paper "Evaluating Introductory Physics Classes in Light of the ABET Criteria: An Example from the SCALE-UP Project" presented in this same session.

7. Improve student attitudes

Results from focus groups and individual interviews have been quite encouraging. Students seem to genuinely enjoy the course and how they were taught, as illustrated in these quotes from transcribed audio tapes:

> "I actually know how I learn through the SCALE-UP physics…through the way that it is set up, through the way they taught us by solving problems. It helped me to learn not so much to get an answer but to actually understand concepts. I also apply that to the rest of my classes. I think from now on, I will do a lot better in my classes just by taking this class-through all the teaching we learned how to solve problems and think through problems."

> "I have studied for a test with some of the traditional 205 students and like they always point to the book for everything, like looking for a formula for everything. Dr. Beichner makes sure that we understand the concept, we can almost derive the formula for whatever we need. And we seem to understand more of the aspects of physics. I definitely feel that, compared to traditional, we have a more in depth understanding and knowledge of what is going on."

In addition to these individual and focus group interviews, we have been measuring student attitudes with the MPEX attitude survey[30] that JMS helped develop. This test not

only examines attitudes about the content of the course, but also students' ideas about science and learning in general. Findings are discussed in the evaluation paper noted immediately above.

8. Promote instructional reform

As noted above, the author has been involved in rewriting a leading physics textbook. Some of the project's hands-on activities have found their way into the revision as "QuickLabs." Many ponderables will appear as a series of "Quick Quiz" questions embedded in the chapters. Beichner is on the steering committee of a national group working to promote the reform on undergraduate physics instruction. He has also given presentations at the recent Sigma Xi Forum on Reforming Undergraduate Education. Team members have given keynote presentations at the American Association of Physics Teacher's New Faculty Workshops. (We feel the work with new faculty is especially important because we can have the greatest impact on teachers who are still forming their own instructional styles.) We also continue giving talks and searching out schools interested in trying our instructional methods. Several of the graduate students involved in the project worked at nearby Duke University, helping them implement the University of Washington's Tutorials and even teaching several sections of their classes. Other team members provided Teaching Assistant training at Duke. We continue to welcome visitors from both large and small institutions. Colloquia and talks at national conferences appear to be working well to stimulate interest in reforming instruction.

III. Conclusions

In summary, we are finding ways to create an active learning environment, even with large numbers of students. We have learned a great deal about the importance of careful design of classroom settings. Because we need to compare to the control group of our traditional students, we are constrained as to how much we can change the overall list of topics covered. Nonetheless, we have been able to add skills like note taking, group work, project planning, evaluation, presentation, and practical lab skills to the more typical objectives of an introductory physics course. We have continued to develop "tangibles" and "ponderables" and students seem to be learning substantially more than in traditional settings, both in terms of conceptual understanding and problem solving ability. During the coming year we plan to develop materials that are especially aimed at helping students with varying learning styles. Other universities continue to be interested in our materials and we are organizing them for paper and web distribution. Additional information is available at www.ncsu.edu/PER.

IV. Acknowledgements

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